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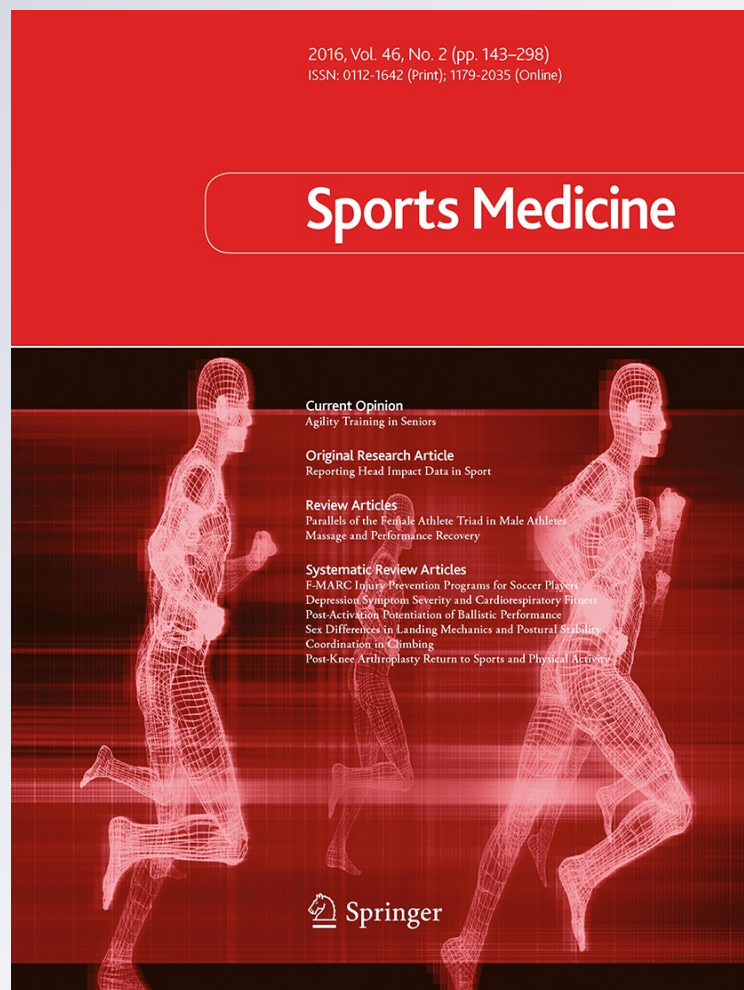
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Exercise-Based Fall Prevention in the Elderly: What About Agility?

Lars Donath¹ · Jaap van Dieën² · Oliver Faude¹

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Abstract Annually, one in three seniors aged over 65 years fall. Balance and strength training can reduce neuromuscular fall risk factors and fall rates. Besides conventional balance and strength training, explosive or high-velocity strength training, eccentric exercises, perturbation-based balance training, trunk strength, and trunk control have also been emphasized. In contrast, aerobic exercise has to date not been included in fall-prevention studies. However, well-developed endurance capacity might attenuate fatigue-induced declines in postural control in sports-related or general activities of daily living. Physical performance indices, such as balance, strength, and endurance, are generally addressed independently in exercise guidelines. This approach seems time consuming and may impede integrative training of sensorimotor, neuromuscular, and cardiocirculatory functions required to deal with balance-threatening situations in the elderly. An agility-based conceptual training framework comprising perception and decision making (e.g., visual scanning, pattern recognition, anticipation) and changes of direction (e.g., sudden starts, stops and turns; reactive control; concentric and eccentric contractions) might enable an integrative neuromuscular, cardiocirculatory, and cognitive training. The present paper aims to provide a scientific sketch of how to build such an integrated modular training approach, allowing adaptation of intensity, complexity, and

cognitive challenge of the agility tasks to the participant's capacity. Subsequent research should address the (1) link between agility and fall risk factors as well as fall rates, (2) benefit–risk ratios of the proposed approach, (3) psychosocial aspects of agility training (e.g., motivation), and (4) logistical requirements (e.g., equipment needed).

Key Points

Agility-based training may integratively improve cardiovascular, neuromuscular, and cognitive function.

This framework considers complex functional tasks, including perception, decision making, reaction, and changes of direction.

Future research should investigate this framework in terms of fall prevention in seniors.

1 Background

Seniors aged >65 years will account for approximately 30 % of the population in Western societies at the end of the twenty-first century [1]. Each year, one-third of those seniors fall and half of those fallers will fall again within the subsequent year [2]. Falls are defined as “unexpected events in which the participant unintentionally comes to rest on the ground, floor, or lower level” [3]. Fall-related injuries are the leading cause of hospitalizations due to injuries [4], lead to increasing healthcare expenditures [5]

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and form a major contribution to years of life lost due to disability [6]. The rate of fall-related injuries increases with age [7].

Numerous personal fall risk factors (e.g., asymmetric and deteriorated maximal and explosive lower extremity strength [8], or impaired postural control [9, 10]) have been identified in the past. Regular strength and balance training has the potential to attenuate aging-induced declines of neuromuscular function [10]. For instance, seniors with well-developed plantar flexion strength, maximal limb muscle strength, and adequate static and dynamic postural control can reduce their fall risk up to 50 % [11]. Such training schemes should be conducted on a regular basis, be embedded into appealing training regimes [12], and use a multicomponent approach [13]. These findings have led to promising best practice recommendations for training interventions targeting fall prevention [14].

2 Exercise-Based Fall Prevention: Available Best Practice Guidelines

Although daily moderate to vigorous physical activity is regarded as a primary preventive strategy to prevent falls in elderly women [15], simply ‘being active’ is not per se an appropriate fall-prevention policy [16]. In 2007, the American College of Sports Medicine (ACSM) and the American Heart Association (AHA) recommended that “to reduce risk of injury from falls, community-dwelling older adults with substantial risk of falls should perform exercises that maintain balance” [17]. Chodzko-Zajko et al. [18] elaborated further on these recommendations 2 years later, emphasizing that “multimodal exercises, including strength and balance training, and Tai-Chi have been shown to be effective in reducing the risk of falls in populations who are at an elevated risk of falling”. At this time, the underlying studies only met evidence level C, pointing to “generally positive or suggestive evidence from a smaller number of observational studies and/or uncontrolled or nonrandomized trials”.

Meanwhile, a Cochrane meta-analysis computed fall rates and risks obtained from 159 studies on fall-prevention interventions in nearly 80,000 community-dwelling elderly [11]. Results showed that multiple-component exercise reduced fall risk by 15 %, irrespective of whether it was completed as home- or group-based exercise. A systematic review by Sherrington et al. [14] corroborated these findings: an overall average fall rate reduction of 16 % [95 % confidence intervals (CI) 9–23] was found after pooling 54 randomized controlled trials (RCTs). A follow-up meta-regression analysis revealed that the highest reductions in fall rates were found when excluding walking (possibly because it causes exposure to fall risk or occurs at the

expense of specific balance training) and including challenging balance exercises on a regular basis for more than 50 h [16]. Interestingly, a more restrictive meta-analysis of 44 trials including exercises (1) with highly challenging balance exercises, (2) with a high dosage, and (3) without walking revealed a reduction of fall rate of 42 % [16].

To translate these findings into specific best practice recommendations for balance training, practitioners should employ exercises that (1) include standing exercises with a gradually reduced base of support (e.g., two-legged stand, semi-tandem stand, tandem stand, one-legged stand), (2) include dynamic movements that perturb the center of gravity (e.g., tandem walk, circle turns), (3) stress postural muscle groups (e.g., heel stands, toe stands), and (4) modify sensory inputs (e.g., standing with eyes closed) [18, 19]. Although less extensively studied, it appears useful to combine gait and balance training with cognitive and/or motor interference tasks [20, 21]. Such dual or multitask paradigms are suitable for both testing and training purposes. Seniors’ static and dynamic balance performance (e.g., spatio-temporal gait characteristics, static balance performance) can be negatively affected by such interference tasks [20, 22]. A withdrawal of cognitive resources for managing the interference task at the expense of postural control seems to account for a higher fall risk in dual-task situations [23]. These current best practice balance training recommendations are summarized in Fig. 1.

Additional resistance exercises have been proposed along with these recommendations for balance training [10]. Resistance training in the elderly has been mostly conducted either as high-intensity training at moderate movement velocity [with 70–80 % of the one-repetition maximum (1RM)] or high-velocity training (i.e., power training) at maximal speed during the concentric phase with 20–80 % of the 1RM (for review, see Granacher et al. [10]). ‘Negative’ resistance training programs, which focus on eccentric work, in view of the possibility to impose high mechanical loads at low energy costs [24], have also been successfully conducted [25]. However, the latter should be implemented very cautiously (e.g., qualified personnel, strong concentrated guidance, specific devices) in terms of minimizing the risk of harmful effects (avoiding incorrect movements and shear forces). Available evidence obtained from randomized controlled trials (RCTs) on traditional resistance training led to the following training prescriptions: strength training performed at least two times per week can yield notable muscle hypertrophy, strength, and power improvements. The training should be performed at moderate to high intensity (i.e., 60–80 % 1RM) and moderate volume (i.e., two to three sets per exercise) [26]. Thereby, six to eight exercises with 8–12 repetitions for each set should be completed. Transfer effects of such resistance training to balance performance seems limited

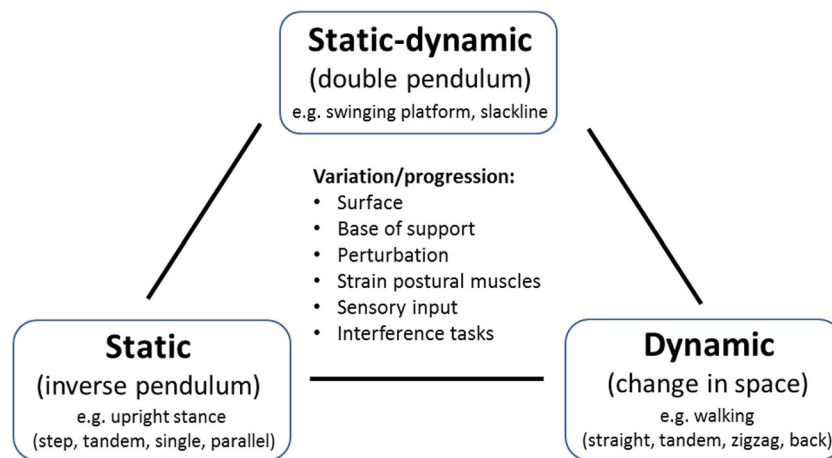


Fig. 1 Aspects and principles of balance training based on Chodzko-Zajko et al. [18], Sherrington et al. [14], Granacher et al. [20], and Muehlbauer et al. [19]. In static situations, balance can be regarded as an inverse pendulum where ankle moments control the center of mass position relative to the base of support, whereas in static–dynamic exercises the body moves as a double pendulum and changes in angular momentum contribute relative to the base of support, and in dynamic exercises changes in location of the center of mass require changes of the base of support. These exercise types should (1) be

applied in both general and high-risk populations, (2) provide at least a moderate challenge to balance, (3) be regularly conducted for 2 h per week in total. Exercise progression can be achieved by varying the (1) surface (e.g., foam, firm, mats), (2) base of support (step stance, tandem stance, single limb stance), (3) perturbations (e.g., at the trunk, leg, shoulder, tripping) (4) loading of postural muscles (e.g., heel stance), (5) sensory input (e.g., deprived vision, acoustic), and (6) interfering tasks (motor and/or cognitive dual or triple tasks)

[27]. However, seniors with higher muscle strength are more likely to regain balance after external perturbations [28]. Consequently, traditional resistance training programs can reduce fall risk and may attenuate the consequences of falls [28]. Therefore, traditional strength training should probably be embedded into multifactorial neuromuscular training approaches but should not serve as the only form of exercise training [10]. The impact of traditional resistance training regimens on rapid force production (explosive power) has been debated in the past. Explosive power is of particular relevance since situations in which balance is threatened require a rapid force production [29], which may not be sufficiently trained within traditional strength training regimens. In response, power and high-velocity training regimes have been introduced and established. Power training had larger effects on force development and physical functional capacity (e.g., floor rise to stand test, 6-min walking test, repeated chair rise test) than traditional resistance training [30]. Power training also beneficially affects maximal strength and can induce transfer effects to balance performance with a lower total training load [10]. As a consequence, the ACSM recommends high-velocity training for the elderly applying one to three sets using light to moderate intensity (40–60 % of 1RM) for six to ten repetitions with high-movement velocity [18]. Recommendations for both maximal strength and power training according to Granacher et al. [10] are shown in Table 1.

3 Agility-Based Exercise for Fall Prevention

Falls in community-dwelling elderly have been reported to be due to a wide range of causes (e.g., tripping, slipping, losing consciousness [hypotension], ‘frozen leg’, loss of support, misstep, pain, and syncope [33]). Among these causes, tripping appears to account for the largest proportion of falls [34–36]. Among seniors residing in long-term care institutions, more than 80 % of falls are attributed to incorrect weight shifting (41 %) or tripping, bumping, and losing support (totaling 43 %) [37]. The effects of strength and balance training on fall risk and rates and the underlying evidence level can be regarded as acceptable (level A or B). The role of adequate endurance in fall prevention has not been sufficiently addressed at present. Inactive seniors might have an elevated relative fall risk when starting to become active. Acute effects of aerobic activities during daily life might also adversely affect postural control, particularly in subjects with less aerobic capacity. There is evidence that fatigue resulting from moderate and heavy bicycle and walking exercise reduces balance performance in seniors [38–40]. Higher aerobic capacity, in turn, may attenuate acute exercise-induced declines of balance performance. Therefore, aerobic training may need to be integrated in fall prevention training programs.

Based on the above, fall prevention likely requires a successful interplay between perception, cognitive function

Table 1 Overview of maximal and explosive strength training recommendations according to Granacher and colleagues [10] and Donath et al. [31]

	Maximal strength training	Explosive strength or power training
Volume	8–12 weeks, approximately 45–60 min per session 6–8 exercises per session 3 sets of 8–12 repetitions	6–12 weeks, approximately 45–60 min per session 6–8 exercises per session 3 sets of 8–10 repetitions
Set break	2–3 min	1–2 min
Frequency	2–3 sessions per week	2–3 sessions per week
Intensity	70–80 % of 1RM 1RM: determined maximal or submaximal ^a based on ratings of RPE between 12 and 16 (Borg scale 6–20)	20–70 % (maximal 80 %) of 1RM 70 % beneficial for explosive strength 20 % for transfer effects to balance based on ratings of RPE between 10 and 13 (Borg scale 6–20)
Velocity	Slow to moderate contraction velocity during eccentric and concentric work	Fast and explosive during concentric work and moderate during eccentric phase

RPE rate of perceived exertion, 1RM one repetition maximum

^a Submaximal 1RM estimations according to Baechle and Earle [32]

(e.g., attention, planning, decision making), neuromuscular performance (trunk, legs), and cardiovascular capacity. Although recent balance and strength training recommendations increasingly emphasize these aspects (e.g., higher velocity and explosive strength training for the legs and the trunk with and without perturbations) [10, 41], best practice guidelines do not completely mirror such considerations. Moreover, current recommendations still tackle balance, strength, and endurance performance separately. Integrative multicomponent exercise training frameworks on fall prevention that address all aspects have not been applied. Recent studies have focused on cognitive aspects concerning decision making employing computer games and tablets, or functional mobility using stepping and obstacle tasks [42–45]. Although these approaches are of a more functional nature and cognitive domains are included, strength and endurance aspects are not sufficiently addressed within these training concepts. Other studies have addressed muscle strength specifically and shown that, for example, explosive strength training with relatively low weights yielded larger effects on force development than traditional strength training [10]. Yet another class of studies addressed balance training programs and demonstrated that balance training can alter spinal reflex circuits, facilitating the neuronal drive to generate higher muscle power [46–48]. In all of these studies, training was one dimensional (e.g., machine training, standing balance training) and stationary, while challenging, functional, comprehensive, and integrative training approaches appeared to be lacking.

Agility-based training approaches comprising accelerations, decelerations, stop-and-go patterns, changes of direction (cutting manoeuvres), and eccentric loads, combined with demanding spatial orientation tasks, may serve as an integrative motor competency training approach for

seniors. Such agility-based training regimens can comprise aspects of perception and decision making (e.g., visual scanning, situational awareness, pattern recognition, and anticipation), movement direction changes (involving reactive motor control and fast concentric as well as eccentric muscle contractions), and cardiovascular training stimuli. A multidimensional exercise profile reflecting the participants' physical performance state can be developed [49]. Physical, perceptual, and cognitive demands of the training modules should become progressively more complex and demanding, and cardiocirculatory demands can also be varied through task choice, circuit length, and number of circuit repetitions. Such an integrative neuromuscular training strategy might serve as a promising, appealing, and time-efficient training regimen within fall-prevention programs in the elderly and may be adaptable to real-life settings. While traditional balance and strength training protocols are frequently considered less specific to situations where balance is threatened (e.g., recovering from sudden perturbations and rapidly producing the required joint moments) [10], and yield task specific training adaptations [50–52] with marginal transfer effects, such an integrative training regimen might bypass these limitations.

Cognitive, physical, vestibular, and proprioceptive functions are necessary prerequisites for ensuring spatial orientation, and these functions decline with aging [53]. Probably, these functions can be integratively trained in such agility-based training approaches. Varying and complex agility patterns including a variety of changes of direction, starts, and stops, are likely to induce slight vestibular perturbations, and challenge proprioceptive and visual control of movement.

An agility circuit can emphasize different motor components at varying levels of difficulty, both physically and

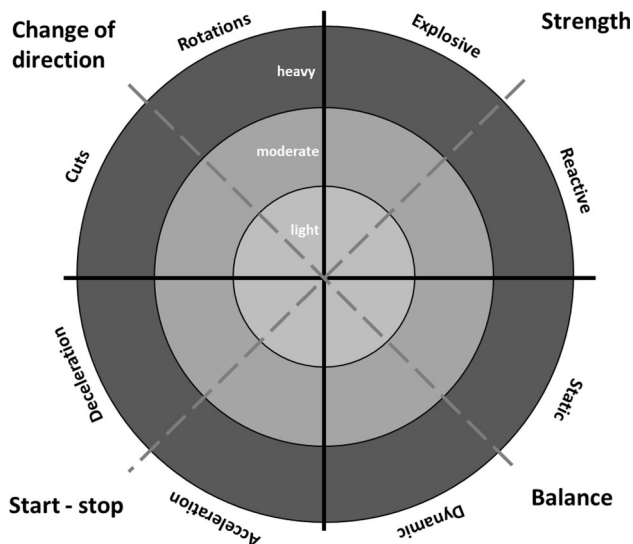


Fig. 2 Modular agility framework including changes of direction, starts and stops, strength, and balance requirements. An example of an agility circuit can accentuate different motor components at varying difficulty levels, physically or cognitively, ranging from light (*light grey*), moderate (*grey*) to heavy (*dark grey*)

cognitively (Fig. 2). The difficulty of the modules can be progressively adapted by (1) surface (e.g., firm, foam, mats), (2) movement velocity (e.g., slow, moderate, fast), (3) movement direction (e.g., forward, backwards, sideways, zig-zag), (4) repetitions (e.g., 5–25), (5) duration (number of agility modules), (6) sets (rounds of the entire agility circuit), (7) type of exercise (easy, complex, stationary, moving, e.g., jumps, skipping, lunges, squats, etc.), (8) interference task (motor, cognitive).

An example of an agility circuit comprising (1) cutting manoeuvres, (2) spatial rotation drills, (3) accelerations and decelerations, and (4) hopping and skipping movements is

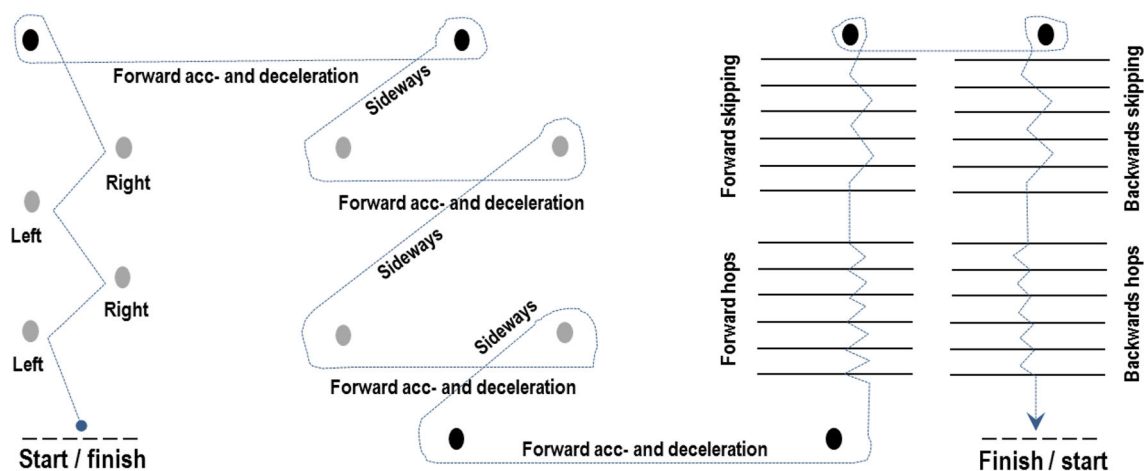


Fig. 3 An example of an agility circuit comprising cutting maneuvers, spatial rotation drills, accelerations and decelerations, and hopping and skipping tasks in different directions

depicted in Fig. 3. The choice and focus of the respective modules and underlying exercise severity can be made depending on individual capacities and motor deficiencies.

4 Conclusion and Outlook

Falls are a serious health issue in increasingly aging societies. Balance and strength training can successfully reduce fall risk factors and fall rates. Endurance aspects have been rarely considered in these training programs, while an adequate aerobic capacity not only improves cardiovascular health but may also be instrumental in fall prevention, as it may attenuate fatigue-related declines of postural control during activities of daily living. Within recent years, high-velocity strength training, eccentric exercises, perturbation-based balance training, and trunk muscle strength and control training have been emphasized. Addressing these issues independently would be very time consuming, and RCTs on these aspects are scarce to date. Thus, it seems reasonable to stimulate agility-based training regimens that aim at improving relevant neuromuscular and cardiocirculatory health parameters in an integrated manner. Such a training concept will enhance aspects of agility, strength, and balance by challenging muscle power, reactive control, and cognitive demands. Trunk and leg muscles would then be challenged in varying movement directions. Modules can be progressively adapted from an easy and short circuit to a challenging and long circuit emphasizing different neuromuscular and cardiocirculatory demands to appropriately address the individual performance abilities.

The proposed conceptual framework should be further examined regarding (1) validity relative to traditional fall risk parameters, (2) benefit–risk ratios of potential

interventional effects in relation to safety issues, (3) psychosocial aspects (motivation, enjoyability, adherence, social interaction) and (4) space and equipment requirements (sports hall, gymnasium).

Compliance with Ethical Standards

This article was written according to the ethical standards of scientific writing and publishing.

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Conflict of interest Lars Donath, Jaap van Dieën, and Oliver Faude declare that they have no conflicts of interest relevant to the contents of this review.

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